7th Symposium on Frequency Standards and Metrology Summary Submission for (invited talk).

Optical Atomic Clocks Based on Laser-cooled Neutral Yb and Ca

C. W. Oates, Z. W. Barber, N. D. Lemke, A. D. Ludlow, N. Poli, L.-S. Ma, T. Fortier, S. A. Diddams, and L. Hollberg

National Institute of Standards and Technology
Boulder, CO 80305 USA
Chris Oates: oates@boulder.nist.gov

We are presently developing two different types of neutral atom optical clocks, which we envision will serve very different applications. One type of clock uses Yb atoms confined to an optical lattice and should enable stable and accurate clock performance; the other uses Ca atoms released from a magneto-optic trap, thereby enabling a comparatively simple and robust but still highly stable optical clock.

While the first generation of lattice clock experiments focused on Sr (at Tokyo, JILA, and SYRTE), Yb offers an interesting alternative due the variety of nuclear spin choices (I=0, 1/2, or 5/2) among its abundant isotopes. We have performed experiments on both even (^{174}Yb, with I = 0) and odd (^{171}Yb, with I = 1/2) isotopes, which have some important trade-offs for clock performance. The even isotope provides simpler atomic structure that is nearly devoid of orientation-related shifts, but it requires use of a modest external magnetic field to induce a non-zero line strength for the clock transition. Otherwise the experiments are quite similar. We use two stages of laser cooling to reduce the atom temperature to ~ 40 μK, a value suitable for loading Yb atoms into a 1-D optical lattice. The lattice is formed by a tightly focused 1-D standing wave whose wavelength, 759.35 nm, is chosen to yield equal Stark shifts for the ground and excited states of the $^1S_0 \leftrightarrow {}^3P_0$ clock transition at 578 nm. The tight confinement provided by the lattice enables long probe times (we have resolved spectroscopic features as narrow as 4 Hz FWHM) and suppresses Doppler effects. We have determined the absolute frequency of the ^{174}Yb clock transition with an uncertainty of 2 x 10^{-15}, which we believe can be considerably reduced with the present apparatus. We will also describe recent frequency measurements with spin polarized samples on the analogous transition in ^{171}Yb.

The Ca clock differs considerably from the Yb clock in that it requires only two (semiconductor-based) laser systems and has a measurement cycle that is 100 times shorter (~ 3 ms). Atoms are loaded from a beam into a magneto-optic trap based on a strong 423 nm transition. The trap is then turned off for about 500 μs, during which the clock transition is probed and the degree of excitation is measured through shelving detection. Because the atoms freely expand, motional effects limit the ultimate achievable uncertainty, but this clock can achieve high stability ($\sigma \sim 3 \times 10^{-15}\tau^{-1/2}$, 10 ms < τ < 200 s) and is user-friendly. It runs on demand and has stayed locked to the Ca clock transition at 657 nm for periods > 10 hours without supervision. We have used this system in conjunction with mode-locked fs-lasers to evaluate systematic effects in other optical clock systems here in Boulder as well as to generate low noise microwaves.